Brien Holden Vision Institute

VASCULAR AND NEURAL SUPPLY TO THE EYE AND ORBIT

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CHAPTER CONTENTS

THE VASCULAR SUPPLY TO STRUCTURES WITHIN THE ORBIT

The blood supply to the orbit involves anastomoses from the internal and external carotid arteries. Virtually all arterial supply to the structures of the eye originates from the ophthalmic artery, the first branch of the internal carotid artery. The external carotid artery normally contributes little to the orbital vasculature but the main branch that arises from it that supplies the orbit is the internal maxillary artery.

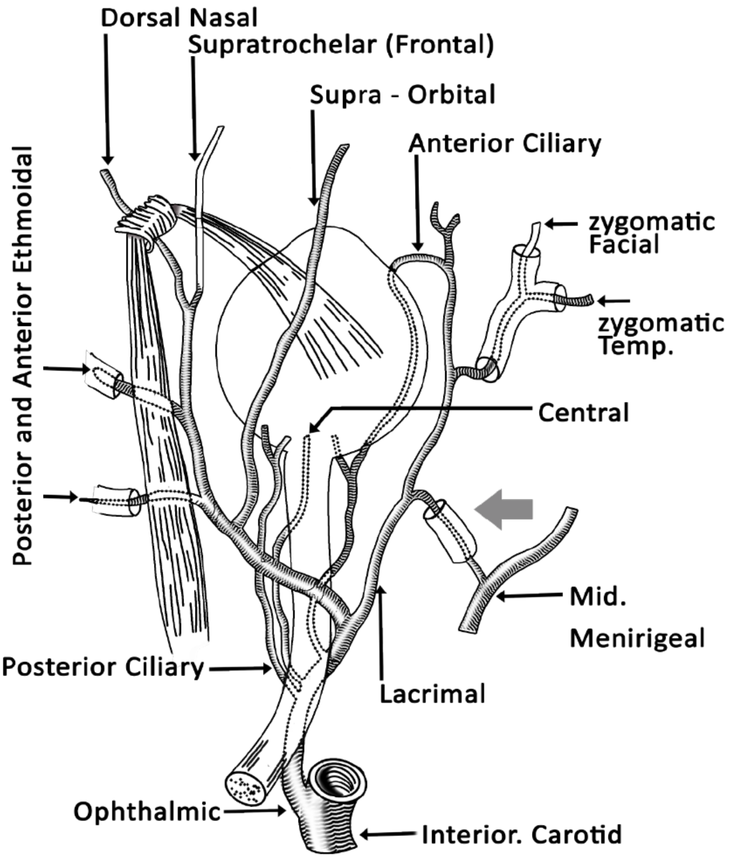

Figure 10.1 : *Vascular supply to the orbit*

The **ophthalmic artery** branches from the internal carotid artery after it exits the cavernous sinus. It then passes forward through the optic canal with the optic nerve on the lateral side. Once within the orbit, the ophthalmic artery runs a short distance below winding around the optic nerve to the medial side. Within the orbit, the ophthalmic artery forms several branches which supply ocular and orbital structures.

Ocular branches of the ophthalmic artery are as follow.

1. **Central retinal artery:** this is the first branch of the ophthalmic artery. It is a slender artery that runs forward, underneath the optic nerve. The central retinal artery pierces the optic nerve about 1.25mm behind the eyeball and runs forward within the optic nerve alongside the central retinal vein. It enters the retina, divides into superior and inferior branches which fan out across the surface of the retina (retinal arcades). It is these branches that are viewed when examining the retina with an ophthalmoscope. The central retinal artery provides vascular supply to the inner layers of the retina (i.e. all retinal layers with the exception of photoreceptors).

2. **Posterior ciliary arteries:** There are three ciliary arteries that supply important structures within the eye:

a. ***The long posterior ciliary arteries***, as the name suggests, forms a long pathway from the posterior to anterior eye. There are usually two posterior ciliary arteries that branch from the ophthalmic artery. They run forward and pierce the eyeball medial and lateral to the optic nerve head. The long posterior ciliary arteries then run forward between the sclera and choroid to the ciliary body. They also anastamose with the short posterior ciliary arteries to provide vascular supply to the outer retina in the periphery (i.e. from the equator to ora serrata).

b. The ***short posterior ciliary arteries*** are about 7 in number and arise from the ophthalmic artery as it crosses the optic nerve. After dividing into a series of branchlets, they pierce the globe around the optic nerve and run within the choroid to supply the outer retina (i.e. photoreceptors) to about the equator. At the equator, the short posterior ciliary arteries anastamose with the long posterior ciliary arteries. The short posterior ciliary arteries form a very important vascular supply to the optic nerve head. A number of the branches that pierce the globe close to the optic nerve form a ring called the Annulus of Zinn-Haller. This is important for supplying the optic nerve anterior to the lamina cribosa. In about 15 to 20% of people, a cilio-retinal artery arises from the ciliary circulation. It enters the retina lateral to the optic nerve and supplies the inner retina between the optic nerve and macula.

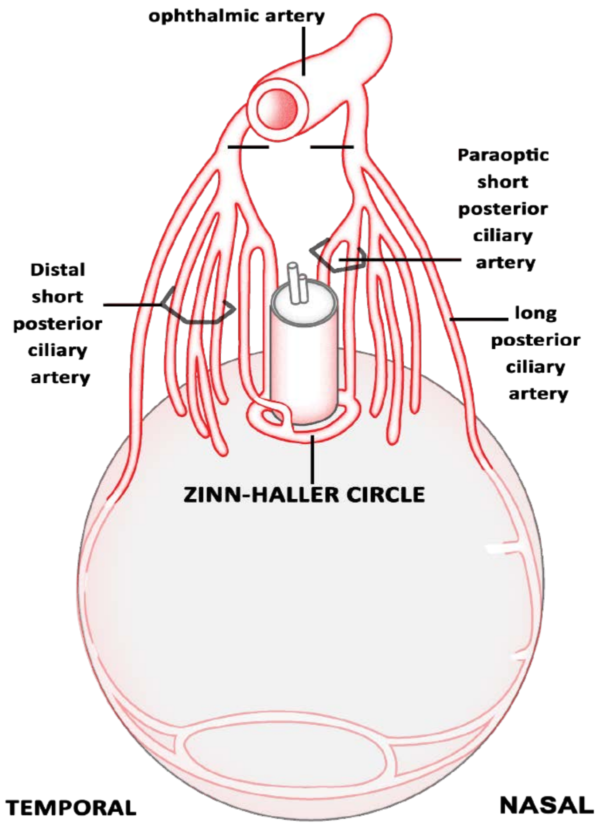

Figure 10.2: *Schematic diagram showing the long and short posterior ciliary arteries entering the posterior eyeball. {Image inspired by http://www.intechopen.com/books/current-basic-and-pathological-approaches-to-the-function-of-muscle-cells-and-tissues-from-molecules-to-humans/choroidal-vessel-wall-hypercholesterolaemia-induced-dysfunction-and-potential-role-of-statins}*

c. The **anterior ciliary artery** is the third of ciliary arteries. This artery supplies anterior structures of the eyeball including the conjunctiva, sclera, and iris. It is a branch of the muscular artery and will be considered in more detail below.

Vascular supply to the optic nerve

There are a number of blood vessels that are closely associated with the optic nerve, and for this reason, we provide a summary of the vascular supply to the different parts of the optic nerve here. As stated above, the short posterior ciliary arteries supply the optic nerve head, specifically the region anterior to the lamina cribosa (Figure 10.3). The remaining optic nerve, posterior to the lamina cribosa is supplied by small branches that arise from the pial vessels or from tiny collateral vessels arising from the central retinal artery.

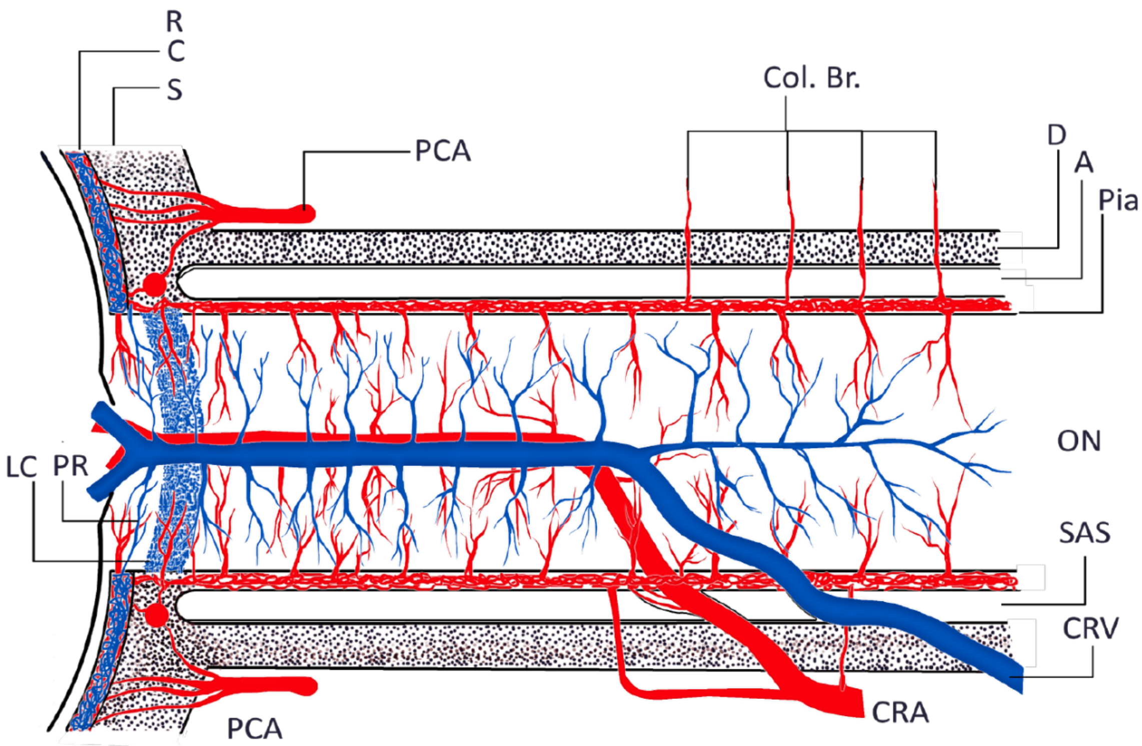

Figure 10.3: *Schematic diagram of the vascular supply to the optic nerve. Image inspired by: {http://www.ijo.in/viewimage.asp?img=IndianJOphthalmol_2011_59_2_123_77024_f1.jpg}*

Vascular supply to the neural retina:

The neural retina receives a dual blood supply. As stated above, the neurons forming the inner retina are supplied by the branches of the central retinal artery, whereas the photoreceptors are supplied by the vessels passing through the choroid, including the short posterior ciliary arteries (from the optic nerve to the equator) and the long posterior ciliary arteries (peripheral retina)

3. **Lacrimal artery:** this is the thickest of the branches of the ophthalmic and passes forward in the orbit along the lateral rectus to supply the lacrimal gland. Branches of the lacrimal artery provide vascular supply to the upper eyelid and conjunctiva.

4. **Muscular artery:** There are a variable number of muscular branches of the ophthalmic artery. These blood vessels travel with the branches of the oculomotor nerve to supply the extraocular muscles. The anterior ciliary arteries originate from the muscular arteries that supply the rectus muscles and form a crucial vascular supply to anterior structures of the eye including the iris, conjunctiva, and sclera. As shown in Figure 10.4, they pass forward and penetrate the sclera to form an anastomosis with the long posterior ciliary artery and major arterial circle of the iris. This has clinical significance when assessing patients with a red eye; indeed circumlimbal redness can be indicative of inflammation within the eye (i.e. uveitis)

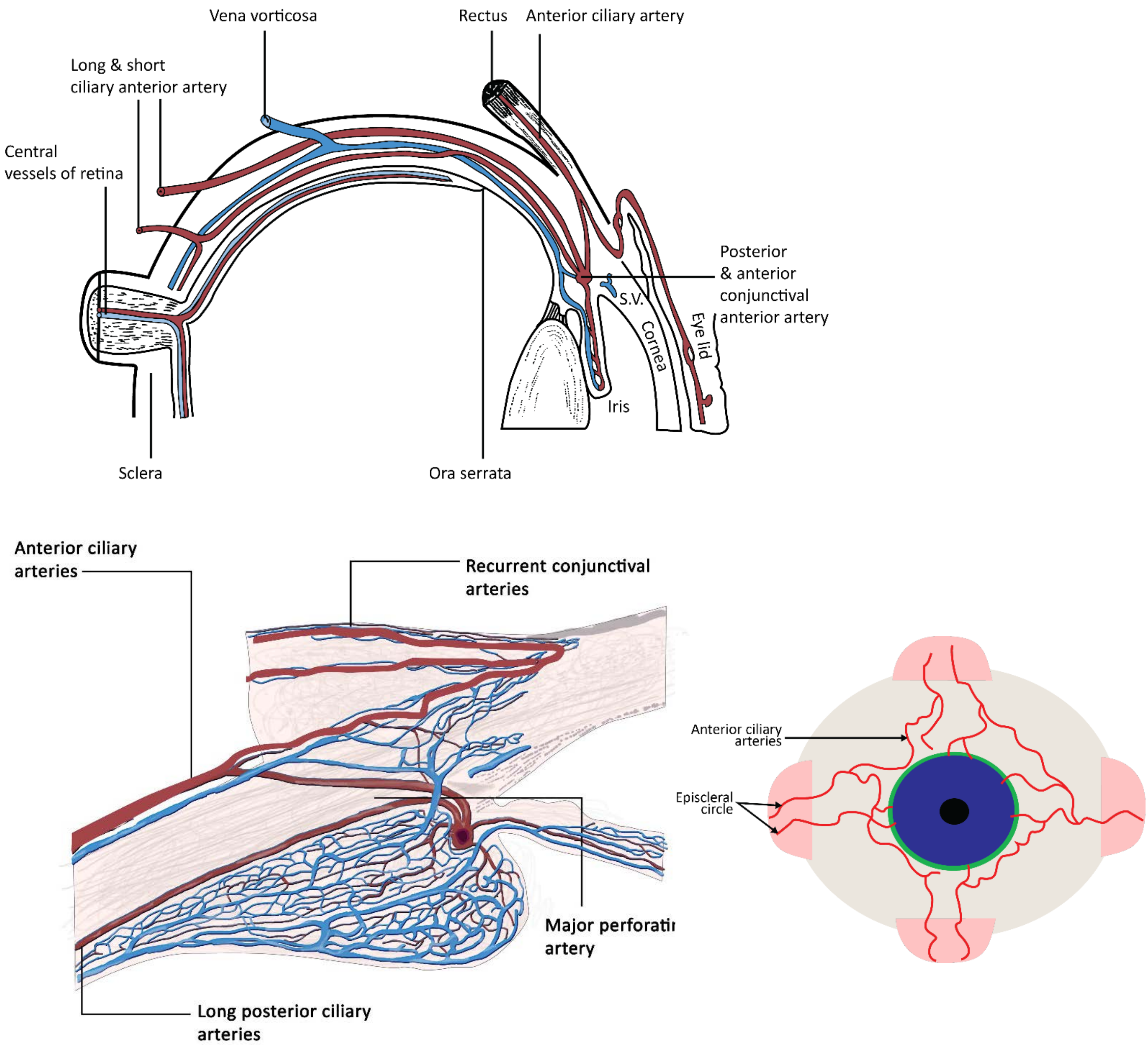

Figure 10.4 (top, left and right): *Blood supply to the eye*

Venous drainage from the eye

Venous drainage from the eye is via a large superior ophthalmic vein and an inferior ophthalmic vein that ultimately drain into the cavernous sinus. The superior ophthalmic vein is formed from the confluence of the angular, supraorbital and supratrochlear veins. It travels posteriorly along the roof of the orbit, before proceeding into the muscle cone where it picks up the venous drainage from the globe via the vortex veins and ciliary veins.

The inferior ophthalmic vein is the main collection vessel for all the smaller veins from the inferior orbit, including the inferior extraocular muscles and inferior vortex veins. It also drains into the cavernous sinus.

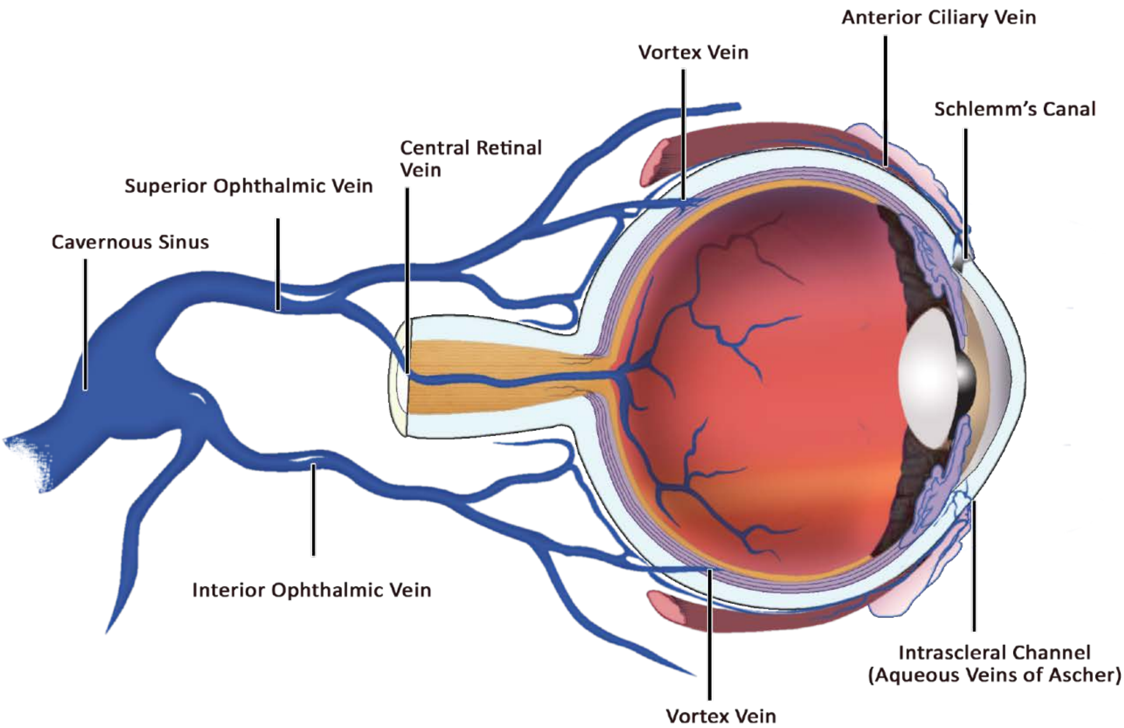

Figure 10.5*: Diagram showing venous drainage from the eye. {image inspired by: http://www.oculist.net/downaton502/prof/ebook/duanes/pages/v3/ch054e/010f.html}*

HISTOLOGICAL STRUCTURE OF BLOOD VESSELS SUPPLYING THE ORBIT

Throughout the body, there are three types of arteries referred to as elastic arteries (e.g. the aorta, pulmonary artery), muscular arteries (virtually all the “named” arteries) and arterioles, which are distinguished by variations in the blood vessel wall.

The blood vessel wall consists of three layers or tunics.

The inner most is the tunica intima that is composed of a single layer of flattened endothelial cells. This layer forms the lining of the blood vessel lumen.

The intermediate layer is called the tunica media and is composed on varying degrees of smooth muscle cells arranged concentrically around the lumen.

The outermost layer is the tunica adventitia, and is composed mostly of connective tissue. Two other layers are important; the internal elastic lamina, located on the outer surface of the tunica intima, is a thin band of elastic fibres that is particularly well developed in muscular arteries. The external elastic lamina is located on the outermost layer of the tunica media and is composed of another band of elastic fibres, although not in all blood vessels.

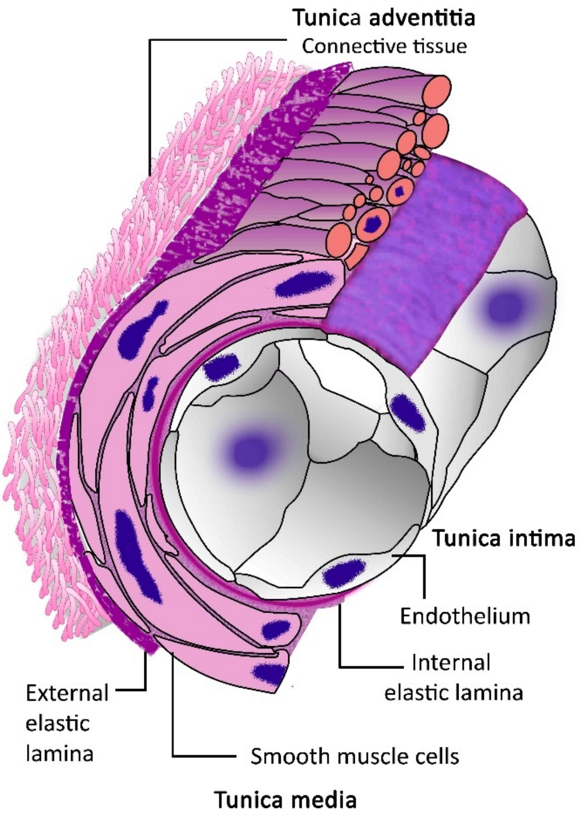

Figure 10.6 *Layers of a blood vessel*

There are three main blood vessel types that are distinguished based on differences in the thickness and composition of the blood vessel wall.

Elastic arteries include the aorta and branches originating from the aortic arch (i.e, common carotid, subclavian). Elastic arteries have thick vessel walls that are characterized by elastic fibres within the tunica media. In addition, they have small nerves that innervate the tunica adventitia (called the vasa vasorum).

Muscular arteries include most of the “named” arteries of the body. They differ from elastic arteries in having a thinner tunica intima, and also a very prominent internal elastic lamina. The tunica media of muscular arteries is composed predominantly of smooth muscle cells that wrap circumferentially around the lumen.

Arterioles are all arteries with a diameter less than 0.1mm. They are composed of a thin vessel wall, consisting of an endothelium, tunica media composed of a single smooth muscle cell layer, sparse internal elastic lamina and scant tunica adventitia.

In the eye, the ophthalmic artery and its branches are all examples of muscular arteries. However, the central retinal artery is in fact an arteriole. This is an important distinction. Notably, the central retinal artery wall has only a single layer of smooth muscle cells, whereas the posterior ciliary arteries have a thicker vessel wall containing a prominent internal elastic lamina and up to 40 layers of smooth muscle cells. In diseases such as giant cell arteritis, known to target the internal elastic lamina and smooth muscle cells, muscular arteries including the short posterior ciliary artery can be affected, whereas the central retinal artery is unaffected. Thus, in patients affected by giant cell arteritis, optic nerve disease can occur, whilst central retinal artery occlusion is unlikely.

LYMPHATICS

The orbit has been traditionally been thought to be devoid of lymphatics. However, more recent studies using selective markers of lymphatic have revealed that they exist in some areas of the orbit, including the lacrimal gland and optic nerve dura.

BLOOD-OCULAR BARRIERS

There are two regions in the eye where there is a blood ocular barrier: the blood-aqueous barrier and the blood retinal barrier. These barriers are so named because they represent regions where there is no diffusion of substances from the blood supply into the tissues. This is an important protective mechanism, where any toxic substance that may pass through the blood vessels does not permeate into the surrounding tissue. However, because of the nature of the barrier, special transporters are expressed on the cells that line the blood vessels to facilitate transport of vital nutrients from the vasculature into the tissues. A clinical example of this is observed when performing fluorescein angiography. Under normal circumstances, sodium fluorescein injected intravenously passes through the vessels of the retina without leakage to the surrounding retinal tissues. In diseases such as diabetic retinopathy, breakdown in the blood retinal barrier occurs resulting in leakage of vascular components into the retina.

The blood-retinal barrier consists of two components. The first component is relative to tight junctions between the RPE cells that lie beneath retina, providing a barrier for any substance passing from the choroidal vasculature into the retina. Thus, the RPE expresses a range of transporters for transferral of glucose, amino acids, lipids, and waste products across the RPE. The second site that is important for creating the blood retinal barrier is the endothelial cells that line the branches of the central retinal artery. Unlike blood vessels in many other parts of the body, the endothelial cells are attached to one another via a series of tight junctions. This forms a tight barrier between anything within the blood vessel and the surrounding tissues.

The blood-aqueous barrier: This also consists of two components. First, there are a series of barriers (tight junctions) between the cells forming the non-pigmented epithelium of the ciliary body. This creates a barrier for any diffusion of solutes from the vasculature within the ciliary body and the posterior chamber. In addition, the blood vessels of the iris are “continuous” vessels like in the retina. The endothelial cells that line the iris vessels are connected to one another via tight junctions that form a tight barrier between the vascular components within the vessels and the iris tissue. This barrier breaks down in diseases such as iritis: leakage of vascular components occurs into the aqueous and can be observed as cell and flare within the anterior chamber.

NEURAL SUPPLY TO STRUCTURES WITHIN THE ORBIT

The twelve pairs of cranial nerves provide motor and sensory information to the face and neck and provide autonomic innervation to structures within the abdomen. These are named rostral to caudal based on the target tissues that they innervate as shown in Figure 10.7. Of the twelve cranial nerves, there are five cranial nerves that provide motor and sensory information to the eyeball. The information provided below includes the functions of each of these five cranial nerves, the location of their nuclei within the brainstem, and brief information of the course through the skull and into the orbit. In particular, information about how the nerves pass through the cavernous sinus is important to understand and also the passage of the nerves through the superior orbital fissure.

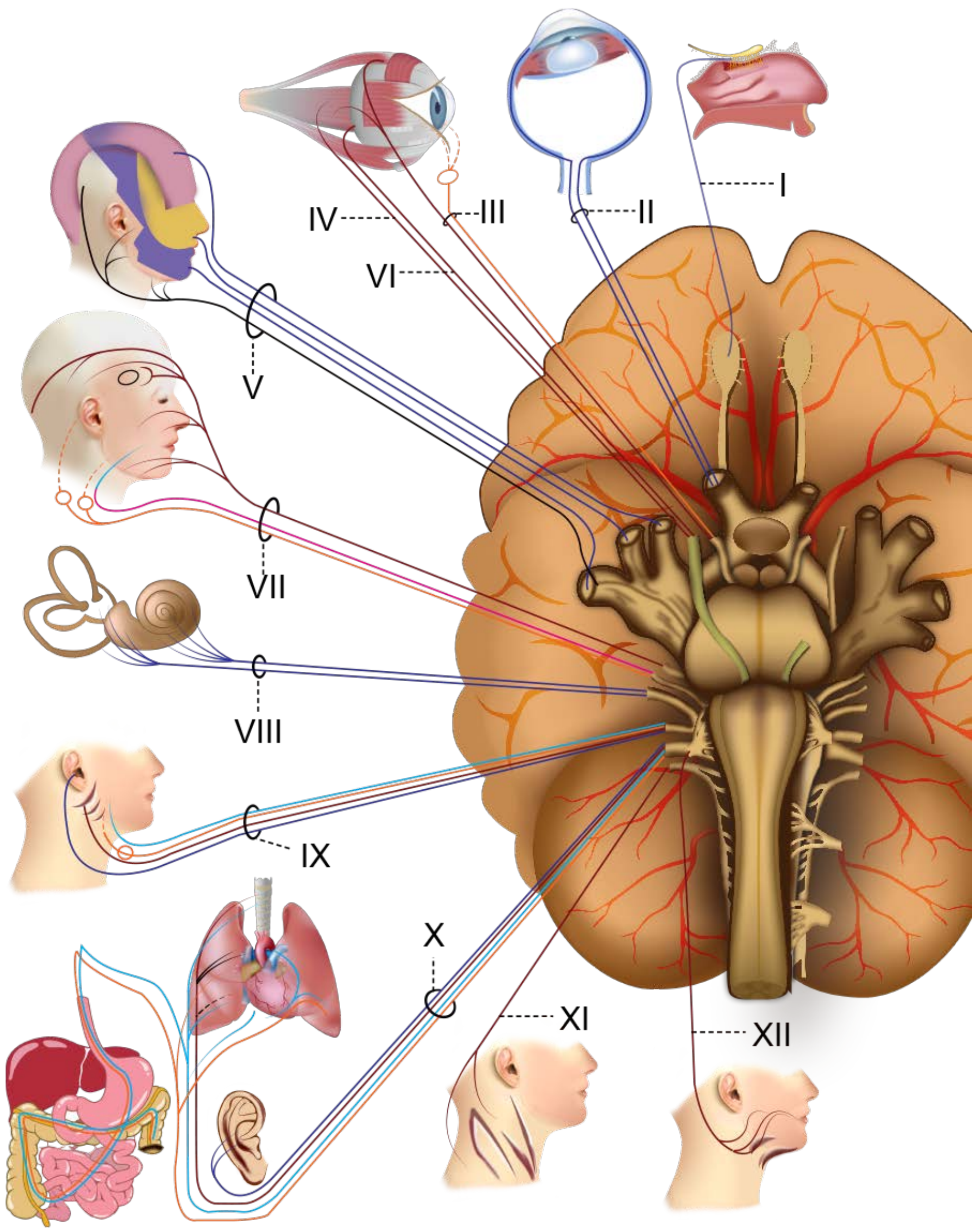

Figure 10.7: *Schematic of the 12 cranial nerves and the structures they innervate. Image inspired by: http://www.proprofs.com/flashcards/story.php?title}*

The **second cranial nerve, the optic nerve**, is formed by the axons of ganglion cells and projects to the Lateral Geniculate Nucleus. It is classes as a special sensory nerve.

The **third cranial nerve, (the oculomotor),** innervates four of the six extraocular muscles (inferior rectus, medial rectus, superior rectus, and inferior oblique) as well as the levator palpebrae superioris of the upper eyelid. It is a somatic motor nerve, which arises from the oculomotor nucleus close to the midline of the midbrain of the brainstem (figure 10.7). Parasympathetic nerve fibres arise from the Edinger-Westfal nucleus of the midbrain and pass forward together with the oculomotor nerve. The oculomotor nerve (and parasympathetic fibres) passes through the cavernous sinus along its wall and then exits the skull to enter the orbit through the superior orbital fissure. It branches into a superior division and enters the superior rectus. The superior branch then passes through the superior rectus and terminates on the levator palpebrae superioris. The inferior branch further divides into three branches, supplying the medial rectus, inferior rectus and inferior oblique.

The **fourth cranial nerve, the trochlear nerve,** innervates the superior oblique. It arises from the trochlear nucleus within the midbrain. The fourth nerve is the only cranial nerve that arises from the dorsal aspect of the brainstem, crossing the midline prior to its exit. Thus, the trochlear nucleus on one side of the brainstem provides innervation to the *contralateral* side. The fourth nerve passes all the wall of the cavernous sinus, exits the skull at the superior orbital fissure, and passes forward in the orbit above the tendinous ring (annulus of Zinn). It then passes medially and superiorly to enter the upper surface of the superior oblique.

The **fifth cranial nerve, the trigeminal**, is the principal somatic sensory nerve to the face (although it also has a small motor branch that innervates the muscles of mastication). The sensory component of the trigeminal nerve is analogous to a primary afferent sensory nerve of the periphery, like a variety of sensory receptors located in the skin, or other structures of the face, that communicate with a nerve whose cell body is located in a sensory ganglia. In the case of the trigeminal nerve, the ganglion, called the trigeminal ganglion, is located lateral and inferior to the sphenoid body in a depression called Merkel's cave. The trigeminal nerve synapses within a large column of the brainstem that extends from midbrain to medulla.

There are three main branches of the trigeminal nerve that provide sensory input from different parts of the face. The Ophthalmic division (V1) of the trigeminal provides sensory information from the forehead up to the apex of the head, contents of the orbit, and side of the nose. The Maxillary division (V2) provides sensory information from the region covering the maxilla (upper jaw and cheeks) and the mandibular division provides sensory input from the mandible (lower jaw). These three divisions converge at the trigeminal ganglion.

The **sixth cranial nerve, the abducens,** innervates the lateral rectus. It arises from the abducens nucleus which is located close to the midline within the pons of the brainstem. The sixth nerve runs through the body of the cavernous sinus, enters the orbit via the superior orbital fissure within the tendinous ring (annulus of Zinn).

The brainstem

In order to understand the passage of the cranial nerves associated with the eye and orbit, it is important to understand the location of the cranial nerve nuclei within the brainstem, how the nerves pass through the cavernous sinus, and finally how they enter the orbit (via the superior orbital fissures). Information about each of these structures is provided below:

The brainstem extends from the mammillary bodies to the pyramidal decussation in the caudal medulla and is anatomically divided into the midbrain, pons and medulla oblongata. It contains the cranial nerve nuclei for cranial nerves 3-12, long fibre tracts that pass through the brainstem from the spinal cord to higher brain centres encoding motor and sensory control of the body, the reticular formation and the main nuclei associated with the cerebellum. The brainstem is crucial for survival, containing the main centres that control respiration, heart rate, a range of complex reflexes as well as a person's conscious state.

The midbrain contains the superior and inferior colliculi (colliculus=hill), important for eye movements and hearing . The oculomotor nucleus is located close to the midline at the level of the superior colliculus, whereas the trochlear nucleus is located at the level of the inferior colliculus. Part of the trigeminal nucleus is located in the midbrain, and is thought to be important for encoding proprioception for structures of the face. Other structures of note in the midbrain include the cerebral peduncles which contain the corticospinal tracts, long white matter tracts that regulate movement of the muscles of the body. In addition, the substantia nigra is located on the ventral aspect of the midbrain, and is important for control of movement.

The pons is located caudal to the midbrain and contains the abducens nucleus. It also houses the nuclei for the 7th and part of the 8th nerve. In addition, the chief sensory nucleus of the trigeminal nerve is located in the pons and is the main input for information relating to fine touch from regions of the face. Other structures of note in the pons include the three large cerebellar peduncles, which are large white matter tracts that communicate information from the cerebellum to other brain regions.

The medulla oblongata is the most caudal region of the brainstem. Its features include nerve nuclei associated with cranial nerves 9-12, extensive regions within the reticular formation that regulate respiration, heart rate and sleep.

The reticular formation, as the name suggests, is a mass of nerve processes that is located within the brainstem. It houses nuclei that are important for regulating the conscious state. In addition, the reticular formation is important for reflexes which involve the cranial nerves. For example, sneezing, crying, hiccupping and laughing are all reflexes mediated by the reticular formation within the medulla. Of note for the eyes is the reticular formation within the pons called the paramedian pontine reticular formation. These nerves regulate the abducens nucleus and are part of the horizontal gaze centre. Similarly, the reticular formation within the midbrain, the mesencephalic reticular formation, forms the vertical gaze centre.

The cavernous sinus

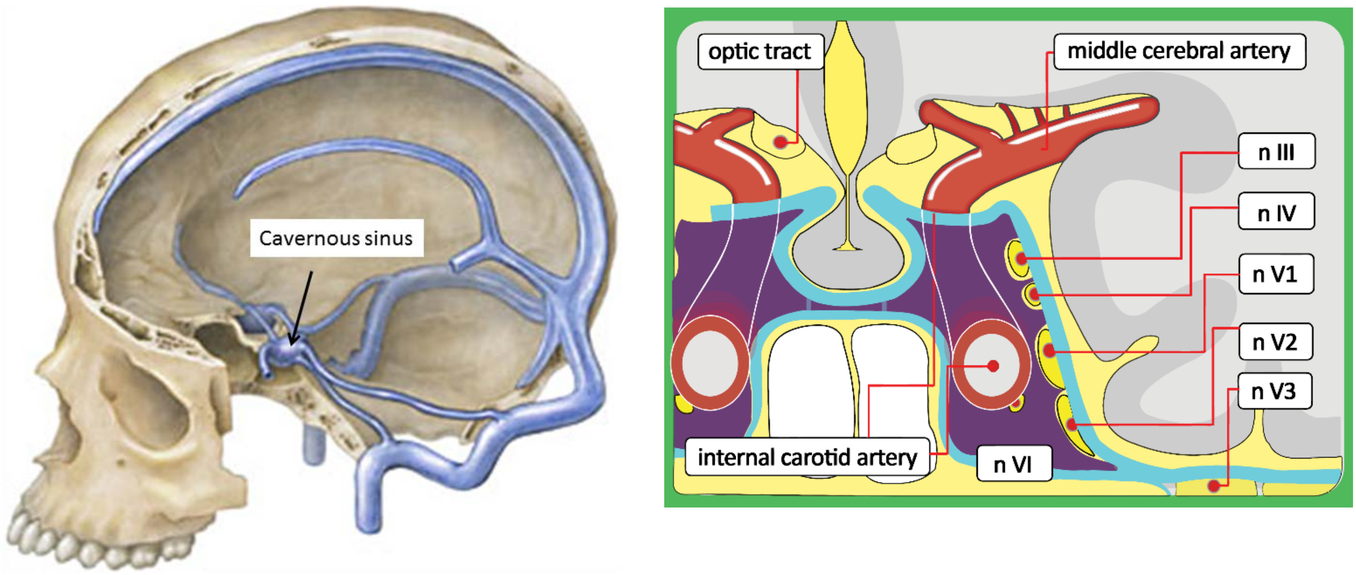

Figure 10.8: *(A) Diagram showing dural venous sinuses of the head (B) Diagram showing the cavernous sinus. Image inspired by: http://www.anatomie-amsterdam.nl/sub_sites/paog_2011/html_pages/information_pages/channels_and_pouches.htm}*

As the cranial nerves associated with the eye pass forward from the brainstem, they pass through the cavernous sinus, a structure located on either side of the sphenoid bone. The cavernous sinus is one of a series of dural venous sinuses. Dural venous sinuses are an important part of the venous drainage system of the brain. Because we hold our heads upright, the brain uses venous sinuses as major drainage points around the brain, rather than large veins (which would collapse under the pressure imposed by the brain). Venous sinuses drain venous blood as well as the corticospinal fluid (fluid that bathes the brain) and passes this through a series of venous sinuses that ultimately drain into the internal jugular veins.

As shown in Figure 10.8, the 3, 4, and 5th (V1 and V2) cranial nerves pass along the wall of the cavernous sinus on each side, while the 6th nerve passes through the middle along with the internal carotid artery.

The apex of the orbit and annulus of Zinn

In order for nerves and blood vessels to enter the orbit, they must pass through one of the fissures-including the superior orbital fissure, inferior orbital fissue or the optic canal. At the apex of the orbit is located the cone of muscles formed by the convergence of the rectus muscles and a common tendinous ring called the annulus of Zinn. Some nerve branches pass through the annulus, whilst others pass forward in the orbit above the tendinous ring.

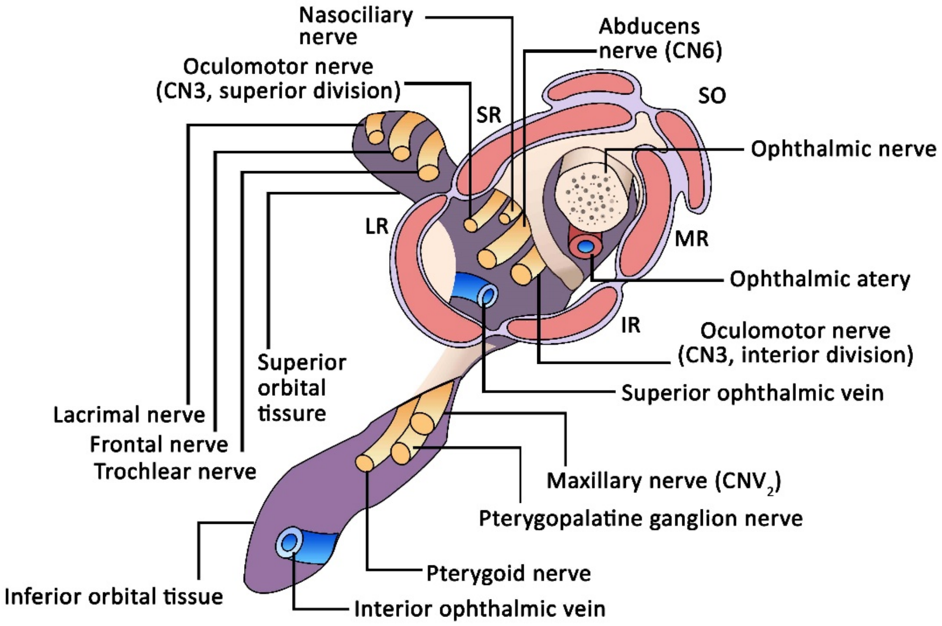

Figure 10.9*: (A) Diagram showing the apex of the orbit, including the superior and inferior orbital fissure, the tendinous ring and the nerves and vessels that pass through each*

The ophthalmic nerve, along with the ophthalmic artery, pass into the orbit via the optic canal. Both divisions of the oculomotor nerve (superior and inferior), the abducens (CN6) and the nasociliary branch of the trigeminal nerve pass through the superior orbital fissure, and then pass through the tendinous ring. The trochlear (CN4), along with the frontal and lacrimal branches of the trigeminal nerve, pass through the superior orbital fissure but then pass forward in the orbit above the tendinous ring. The maxillary division of the trigeminal passes through the inferior orbital fissure along with parasympathetic fibres.